Research Program

Climate and Carbon Sciences Program

Margaret S. Torn

510/486-2223
mstorn@lbl.gov

ESD's Climate and Carbon Sciences Program (CCS) is an integrated program that seeks to understand the physical, chemical, and biological processes affecting the Earth's atmosphere, land, and oceans. CCS conducts research into how Earth's processes may be affected, either directly or indirectly, by changes in radiative forcing of climate resulting from energy production and use. In addition, program research on biogeochemical cycles and climate also addresses other pressing issues such as stewardship of water resources and the environmental effects of biofuels. To that end, we have active projects on climate and hydrology, climate change, terrestrial and marine biogeochemistry, and carbon sequestration by terrestrial ecosystems. Note that after seven years of successful expansion, in 2007 the Climate Change and Carbon Management Program was divided into two programs, Climate and Carbon Sciences (summarized below) and one for Geologic Carbon Sequestration (summarized elsewhere in this volume).

CCS is also poised to develop new areas of climate science, including research in biofuels and alternative energy, subsurface hydrology, computational mathematics, and other fields. CCS has several significant research initiatives in these areas, with demonstrated potential to make vital contributions to BER's climate change portfolio. These include:

- The conceptual design of a Center for Integrated Earth System Modeling
- New methods for measuring and understanding the stabilization of soil organic matter and ecosystem feedbacks to climate change
- Regional hydrometeorology and the hydrological impacts of climate change

In the fall of 2007, the Program hosted a multinational lab workshop on abrupt climate change. The product of this workshop was the beginning of a large, long-term, interdisciplinary DOE-funded project that will greatly improve our ability to predict the probability of abrupt climate change—using a set of five different mechanisms, from ice-shelf disintegration to high latitude ecosystem response.

SCIENTIFIC FOCUS AREAS

CCS investigations span and integrate all four DOE Basic Energy Research Office (BER) Scientific Focus Areas (SFAs) in climate change:

1. Climate Change Forcing
2. Climate Change Modeling
3. Climate Change Response
4. Climate Change Mitigation

Each of these SFA's is discussed in greater detail below.

Climate Change Forcing

The goals of Berkeley Lab's terrestrial carbon research include supporting the development, testing, and application of Integrated Terrestrial Carbon Models (ITCMs) that will be used to simulate carbon fluxes in North America in the near term, and coupled with global climate models in the long term.

This work is a multi-institution collaboration under the coordination of the lead lab in this SFA, Oak Ridge. Berkeley Lab is pursuing five areas of research relevant to improving carbon cycle understanding: (1) better characterization of ecosystem CO_2 fluxes and resulting atmospheric concentrations; (2) spatially and temporally resolved measurements of fossil CO_2 emissions; (3) better understanding of soil carbon cycling; (4) simulation of feedbacks between carbon dynamics and climate change in global carbon-climate models; and (5) diagnosis of carbon modules in global climate models using AmeriFlux, North American Carbon Program (NACP), and other carbon system observations.

CCS is also carrying out innovative observations of the ocean carbon cycle that would contribute to removing a major gap in coupled carbon-climate modeling. Oceans contain more carbon than any other dynamic reservoir on earth. They pose a great observational challenge because the pulses of biological productivity are episodic and cover vast areas. CCS scientists have developed the Carbon Explorer, an autonomous float that uses satellite telemetry to report its observations from distant oceans. Twelve of these low-cost robots have achieved the equivalent of 8 years of continuous observations of particulate organic carbon in remote and biologically dynamic ocean regions, observations that would not have been possible with conventional research ships. Seagoing work to prove and enhance new sensors for the Carbon Explorer is ongoing. CCS's new sensor for particulate inorganic carbon was operationally deployed to full ocean depth during a pole-to-pole survey transects of the Atlantic Ocean in July 2003 and January 2005. The data it reported allow the first comprehensive examination of the spatial variability of particulate organic and inorganic carbon. CCS's optical carbon sedimentation recorder was most recently deployed in Oyshio waters near Japan.

Climate Change Modeling

Simulations from global models provide critical information required to attribute past climate change and ameliorate future climate change. Despite the sophistication of current coupled climate models, they will benefit from inclusion of biogeochemical feedbacks, improved spatial resolution, and an understanding of abrupt climate changes. To understand the role of these processes in regional and global climate change, the climate community should develop Earth System Models (ESMs) designed to simulate the coupled physical, chemical, and biogeochemical evolution of the environment. It is increasingly critical to project local extremes in precipitation and other weather conditions forced by climate change. However, these projections are subject to large uncertainties, driven by specific uncertainties in model physics and restricted model resolution. Uncertainty reduction hinges, in part, on site-to-regional-scale process-based studies leading to new parameterizations in ESMs, analysis of model-simulated atmospheric physics and dynamics with observational evaluations, and high-resolution studies of the space-time evolution of extremes and anomalous weather and climate states. New research is needed to understand whether projections of extremes can converge with better process fidelity and higher spatial resolution.

Climate Change Response

To guide DOE energy policy decisions, we need integrated economic analyses of climate change, based on both projections of climate impacts and mitigation/adaptation analyses for biofuel and fossil fuel emissions (for GHGs and aerosols). Integrated models that address both the socio-economic and environmental impacts of energy and land-use systems, at a spatially disaggregated scale with temporal feedbacks, are lacking in current analyses.

Toward meeting this need, the physical impacts of climate variability and change (floods, droughts, heat waves, electricity demand) are a major modeling and analysis component at Berkeley Lab. Work within CCS on these impacts (by Miller and Jin) has appeared in the 2nd, 3rd, and 4th Intergovernmental Panel on Climate Change (IPCC) Assessment Reports, as well as the U.S. Global Change Research Program Assessments. Their research is focused on understanding regional impacts and reducing uncertainty across scales, and includes important studies of climate change impacts on alpine hydrology and snowpack. These activities, along with the DOE Water-Energy Nexus, have helped to develop the important physical-economic linkage for integrated assessment. Miller and Jin have quantified the range of possible extreme heat days and coupled energy demand, projected demand, and supply availability. New work includes development of heat day simulations and new building codes for cooling/heating.

Climate Change Mitigation

Limitations in current soil carbon models cripple scientists' ability to predict climate effects on CO_2 fluxes or to evaluate carbon sequestration and land management strategies. Four major gaps in the understanding of soil carbon dynamics have been identified (e.g., by BERAC, DOE, and USDA) that are important for both coupled climate-carbon modeling and carbon management, and that can be addressed in the next 5 years. Specifically, the priority areas for soil carbon research are (1) the effect of plant allocation and species on carbon residence time; (2) physical protection of soil organic matter, by minerals and aggregation; (3) temperature and moisture interactions; and (4) testing and improvement of model performance. We have in hand sufficient understanding and data to begin developing much improved model parameterizations for several of these areas.

Partnerships and Funding

Underlying all this work are CCS's active partnerships with universities, industry, and other research laboratories. Key among these is our strong partnership with UC Berkeley, which includes collaboration with faculty, sharing research facilities, teaching, advising and mentoring UC students, and interaction with the Berkeley Atmospheric Sciences Center, Berkeley Water Center, and Berkeley Institute of the Environment. We have exciting new research projects on biofuels starting under the aegis of the Energy Biosciences Institute.

The Climate and Carbon Science Program is funded by a variety of federal and state agencies, and international collaborations. The most important sponsor is the U.S. Department of Energy, through the Office of Biological and Environmental Research, Office of Basic Energy Sciences, and Office of Fossil Energy. Valuable support also comes from the National Aeronautics and Space Administration; National Science Foundation; National Oceanographic and Atmospheric Administration, as well as the California Energy Commission, CAL-FED, and the Energy Biosciences Institute.

Understanding the Role of Land-surface Processes in the Regional Climate System: A WRF Modeling Study

Jiming Jin, Norman L. Miller, and Nicole J. Schegel
Contact: Jiming Jin, 510/486-7551, JimingJin@lbl.gov

RESEARCH OBJECTIVES

The state-of-the-art Weather Research and Forecasting (WRF) model, developed by the National Center for Atmospheric Research (NCAR), is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict regional weather and climate. The current-release version (2.2) of the WRF model includes three land-surface schemes—the simple soil thermal diffusion (STD) scheme, the Noah scheme, and the Rapid Update Cycle (RUC) scheme. We have recently coupled the sophisticated Community Land Model version 3 (CLM3) to WRF to better simulate and predict snow, vegetation dynamics, and related processes. The objective of this study is to quantify the role of varying levels of complexity in land-surface processes in the regional climate system, by performing a series of WRF runs with these four land-surface-scheme options. Among these four schemes, the STD scheme is the simplest one (both in structure and physics), CLM3 is the most sophisticated, and the complexity level of RUC is comparable with that of Noah. The modeling analysis shown in this study also gives insight into how the land-surface-scheme complexity level affects the accuracy of regional climate simulations.

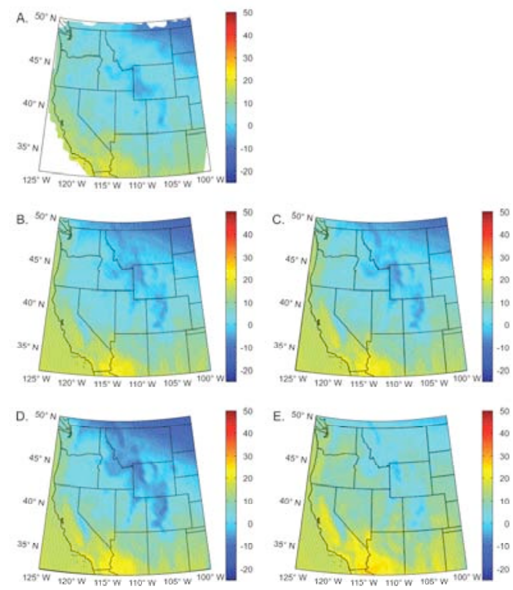

Figure 1. The geographic distribution of observed and WRF simulated winter (December, January, and February) daily maximum temperature (Unit:°C). A. Observations; B. CLM3; C. Noah; D. RUC; E. STD

APPROACH

Four WRF simulations, one for each land-surface scheme, were generated with a 30 km resolution domain that focuses on the western United States. Each simulation period was for 1 October 1, 1995, through September 30, 1996. The National Centers for Environmental Prediction–Department of Energy (DOE) Reanalysis (NCEP-2) data were used for the WRF initial and lateral boundary conditions, with the boundary forcing, including sea surface temperature (SST), updated every six hours.

ACCOMPLISHMENTS

The WRF simulations indicate that the most sophisticated land-surface model, CLM3, generated the best temperature simulations when compared to the results from the other three land surface models. The simplest model (STD), without a snow and vegetation component, produces the worst results. Figure 1 shows the winter daily maximum temperature observations and simulations. The domain-wide averaged value for the observation is 5.5ºC, and for WRF-CLM3 is 5.0ºC. The daily maximum temperatures for RUC, NOAH, and STD with WRF are 4.9ºC, 6.2ºC, and 10.4ºC, respectively. The simulated geographic distributions of temperature for all these models are quite similar, implying that the temperature distribution is more closely related to the atmospheric forcings than to the land-surface processes, whereas the temperature magnitude is dominated by land-surface characterizations. In addition, WRF dramatically overestimates precipitation, especially over complex topography in the western U.S. no matter which land-surface model is chosen, indicating that precipitation simulations are strongly connected with atmospheric processes over this region.

SIGNIFICANCE OF FINDINGS

The results from WRF with these land-surface schemes show that land-surface processes strongly affect temperature simulations; the WRF-CLM3 with the highest complexity level produces the best results. Precipitation is dramatically overestimated by WRF for all of the land-surface schemes over the western U.S. analyzed here, and does not show a close relationship to land-surface processes.

RELATED PUBLICATION

Jin, J., N. L. Miller, and N. Schegel, Understanding the role of land-surface processes in the Regional Climate System: A WRF modeling study. Proceedings of the Annual WRF Workshop, Boulder, Colorado, 2007.

ACKNOWLEDGMENTS

Support for this work provided by the California Energy Commission under Grant 500-02-004. Work performed at Lawrence Berkeley National Laboratory was supported by the Director, Office of Science, Office of Biological and Environmental Research, Climate Change Research Division, Atmospheric and Radiation Measurement Program, of the U.S. Department of Energy under Contract No. DE-AC03-765F0098.

Regional Climate Simulations to Quantify the Range of Land-Use Change and Impacts on Hydroclimate in the California Central Valley

Jiming Jin[1] and Norman L. Miller
[1]Utah State University, Logan, Utah
Contact: Jiming Jin, 435-797-8175, jiming.jin@usu.edu

RESEARCH OBJECTIVES

Over the last century, more than half of the California Central Valley area has been converted to agricultural area since the presettlement period. Understanding how and to what extent such land-use change affects local climate and ecosystems is critical to the economy of California, because the Central Valley produces one-quarter of the agricultural products in the United States, with an annual income exceeding $26 billion and an export revenue exceeding $6.7 billion. In this study, we use an advanced regional climate model to quantify the range of land-use change its impact on the local climate.

APPROACH

The regional climate model used here is the nonhydrostatic version of the fifth-generation mesoscale model (MM5), version 3.7, developed by the Pennsylvania State University/National Center for Atmospheric Research (NCAR). We have coupled MM5 with the advanced NCAR Community Land Model version 3 (CLM3) (Jin and Miller 2007) to improve land-surface process simulations and forecasts. Two runs were performed with MM5-CLM3. The first run was forced with the modern-time land-use types that are the 24 U. S. Geological Survey (USGS) land-use types. The second run was forced with the presettlement-time land types that were created from the Olson Global Ecosystems data.

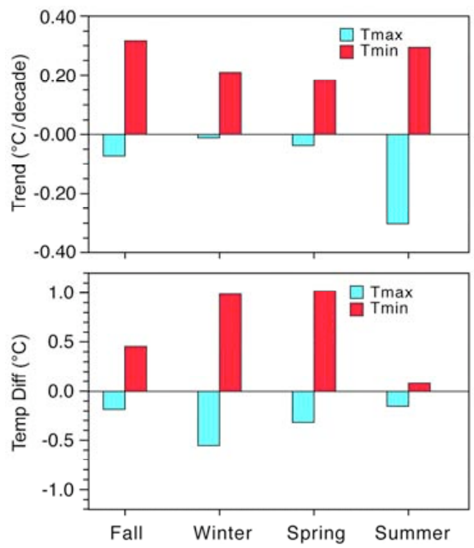

Figure 1. (a) Observed seasonal Tmax (blue bars) and Tmin (red bars) trends over the California Central Valley for the period of 1910-2003; (b) The daily Tmax (blue) and Tmin (red) differences between the modern time and presettlement time runs (Modern–Presettlement) for the period of 1995 and 1996.

ACCOMPLISHMENTS

The observed temperature trends for the Central Valley indicate that daily maximum temperature (Tmax) has a negative (cooling) trend in all seasons (blue bars in Figure 1a) over the last century, with the strongest negative trend in the summer (0.30ºC/decade), and the weakest trend in the winter (-0.01ºC/decade). The daily minimum temperature (Tmin) has a significant positive trend for all seasons (red bars in Figure 1a). The simulated temperature changes (Figure 1b) agree well with the observations. Tmax decreases in the Central Valley over all four seasons in the modern time run, with the strongest decrease (-0.55°C) occurring in winter, as compared with that in the presettlement run. In the mean time, the modern time Tmin increases by more than 0.40ºC in the fall, and by approximately 1ºC in the winter and spring; whereas in the summer, Tmin shows little change (~0.08°C). Detailed analysis shows that the temperature changes are caused by the sensible heat flux variations, in turn caused by the lower roughness length in the modern time than in the presettlement time over the Central Valley, where the grassland and trees have been converted to cropland and bare soil over the last hundred or so years.

SIGNIFICANCE OF FINDINGS

Our modeling results are consistent with the observations. Temperature variations are found to be related to the sensible heat flux changes caused by the lower surface-roughness length in the modern time than in the presettlement time. This study indicates that during the day, land-use change in the Central Valley overcomes the global warming signal and dominates the temperature change, whereas at night, land-use change strengthens such greenhouse-gas related warming.

RELATED PUBLICATION

Jin, J., and N. L. Miller, Regional climate simulations to quantify the range of land-use change and irrigation impacts on hydroclimate in the California Central Valley. Journal of Geophysical Research (in review), 2007.

ACKNOWLEDGMENTS

Support for this work is provided by the California Energy Commission under Grant 500-02-004. Work performed at Lawrence Berkeley National Laboratory was performed under Contract No. DE-AC02-05CH11231.

Climate Change Projected Fire Weather Sensitivity: California Santa Ana Wind Occurrence

Norman L. Miller and Nicole J. Schlegel
Contact: Norman L. Miller; 510.495.2374/nlmiller@lbl.gov

RESEARCH OBJECTIVES

California coastal-region, wildfire-weather conditions typically occur during the fall prior to winter rains, when an inland high pressure and an offshore low pressure set up a strong pressure gradient, resulting in high offshore winds, heated air mass, and low humidity. These conditions are known locally as Santa Ana winds in southern California and Diablo winds in northern California, but are more generally defined as foehns. Such weather conditions have a long history of being associated with high winds that spread fires. The objectives of this study are to determine climate-change-related shifts in the occurrence of Santa Ana wind conditions.

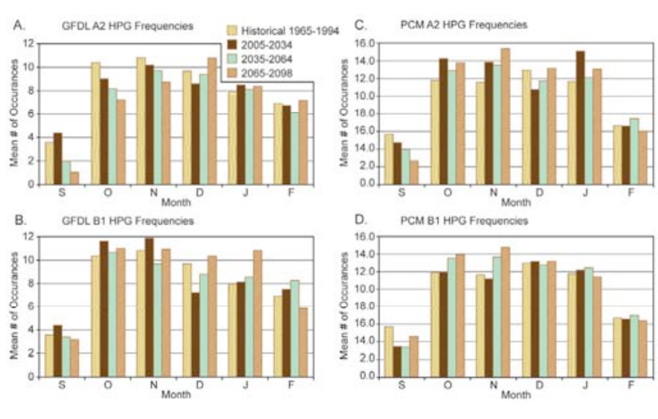

Figure 1. AOGCM pressure-only derived SAO sensitivity for 2005-2034, 2035-2064, and 2070-2099 based (A) GFDL A2, (B) GFDL B1, (C) PCM A2, and (D) PCM B1.

APPROACH

A new method based on atmosphere-ocean general circulation model (AOGCM) surface pressure gradients was developed for identifying coastal high-wind fire-weather conditions, such as the Santa Ana Occurrence (SAO). We use the low- and mid-range temperature-sensitivity National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM) and the National Oceanic & Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory version 2.1 (GFDL) climate models, forced by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) high (A2) and low (B1) emissions for three 30-year mean-monthly climatologies—2005–2034, 2035–2064, and 2070–2099. These scenarios represent the range of IPCC nonintervention emissions futures, with atmospheric CO_2 approaching 550 ppm (B1) to 830 ppm (A2) by 2100. The surface-pressure difference criterion was applied to AOGCM historical and projected output to determine the percent change in occurrence of simulated SAOs. AGCM-simulated 30-year mean-monthly climatologies for 1965–1994 were compared to SAO climatologies based on the observed wind direction and humidity, and showed good correlation.

ACCOMPLISHMENTS

The sensitivity of climate-change-projected SAOs was analyzed using AOGCM output from the low-temperature sensitivity PCM and middle-temperature sensitivity GFDL, with low-to-high emission scenarios. The trends match well, with September having the lowest number of SAO days, an increasing trend toward the maximum in December, and a decreasing trend for the period during January and February.

This climate change analysis shows consistent shifts in the maximum number of SAO events from September-October to November-December, suggesting SAOs may significantly increase the extent of California coastal areas burned by wildfires, loss of life, and property.

More research is required to fully establish the sensitivity of this mechanism under greenhouse gas forcing. Pressure and sea surface temperature (SST) variability are teleconnected to SAOs, and this remains poorly understood. The role of natural variability and climate change in ocean temperatures plays a significant role in the strength and increase or decrease of the number of SAOs. Further analyses of natural climate modes and variability will need to be carried out to fully understand this sensitivity.

SIGNIFICANCE OF FINDINGS

This study suggests there may be SAO increases during critical dry periods, especially late in the season, leading to more extensive wildfires. These initial findings indicate striking differences between early century and late century, and high-emission and lower-emission SAO sensitivities, with shifts in SAOs from earlier to later in the year that are greater under A2 relative to B1 and GFDL relative to PCM, and with no clear changes in the January to February SAOs.

RELATED PUBLICATION

Miller, N.L. and N.J. Schlegel, Climate change projected fire weather sensitivity: California Santa Ana wind occurrence. LBNL-61004. Geophysical Research Letters, 33, L15711, doi:101029/2006GL25808, 2006.

ACKNOWLEDGMENTS

Support for this work is provided by the California Energy Commission and by the California Environmental Protection Agency as a contribution to the Governor's Climate Science Report. Work performed for the Department of Energy at Berkeley National Laboratory is under Contract No. DE-AC02-05CH11231.

Climate-Change-Related Extreme Heat, Mortality, and Energy Demand

Norman L. Miller, Jiming Jin, Katharine Hayhoe, and Max Auffhammer
Contact: Norman L. Miller; 510.495.2374/nlmiller@lbl.gov

RESEARCH OBJECTIVES

As the southwestern U.S. becomes more populated, and extreme heat days more frequent, electricity demand for cooling will continue to rise. Electricity supply failures have occurre d during recent extreme summer heat events. In 2006, Sacramento exceeded 110°F for 10 days. The objectives of this study are to quantify the projected increases in the frequency, intensity, and duration of extreme heat days and evaluate the impact on the energy sector from increased demand for cooling.

APPROACH

Extreme heat days are defined here as the warmest June to September (JJAS) days for 1961–1990 exceeding 90 percent (T90) of the summertime daily maximum temperatures at a given location. A heat wave is defined as 5 consecutive T90 days. We calculate the number of projected JJAS days at or above the historical T90s, an important metric used in California energy capacity analysis also referred to as the 1-in-10 high-temperature days. We also calculate standardized JJAS cooling degree-days as defined by the National Climatic Data Center; CDD = (Ta-Tac) days, where Ta is the daily mean near-surface air temperature, Tac is an average daily-mean temperature threshold for human thermal comfort, and days is the number of days with temperatures exceeding Tac.

ACCOMPLISHMENTS

We evaluated the number of maximum temperatures days projected to exceed the 1960–1990 T90 threshold, at the California state level and for the five urban centers within California. California's historical T90 (35ºC), is projected to double from 12 days to about 24 days by 2005–2034, regardless of the emissions scenario. By 2035–2064, this increases to 27–39 days (B1), 29–47 days (A2), and 32–66 days (A1fi). By 2070–2099, the statewide T90 days are projected to increase an average of 4 times (B1), 5.5 times (A2), and 6.5 times (A1fi) relative to 1960–1990 (Figure 1). City-specific T90 values are for San Francisco, Los Angeles, Sacramento, Fresno, and San Bernadino. The period 2070–2099 is projected to increase by 3.5 to 4 times under B1, 5.5 to 6 times higher under A2, and 6 to 7 times under the higher A1fi scenario, depending on the city. Historical California CDD values average 400–500°C-days/year, are projected to increase to 600–1000°C-days by 2035–2064, and by 2070–2099 increase to 650–1000°C-days under the B1 scenario; and up to 800-1250°C-days and 1000-1500°C-days under the higher A2 and A1fi scenarios, respectively (Table).

Together, the impact of projected increases in T90 frequencies and duration will significantly increase peak electricity demand. Peak electricity demand increases under all climate change scenarios, with residential peak electricity demand at mid-century increasing by 3.4–10.0 percent under the A1fi and A2 scenarios and by 2.8–7.7 percent under the B1 scenario.

SIGNIFICANCE OF FINDINGS

Projected increases in extreme temperatures and direct estimates of electricity demand suggest that electricity demand in California is likely to continue to rise over this century, even without considering likely population growth. Although California's installed electricity capacity will also continue to grow over time, its current rates of growth suggest summer electricity shortages may occur.

	1961-1990 (absolute value)	2035-2065			2070-2099		
		A1fi	A2	B1	A1fi	A2	B1
San Francisco	60	+90-150	+90-100	+60-90	+260-340	+140-220	+110-150
Los Angeles	570	+190-340	+210-310	+150-200	+410-590	+260-550	+230-310
Sacramento	690	+310-400	+270-360	+220-280	+630-720	+310-630	+330-410
San Bernardino/Riverside	800	+250-430	+200-410	+190-270	+520-750	+240-750	+290-390
Fresno	900	+320-410	+200-370	+220-310	+640-730	+250-670	+340-410

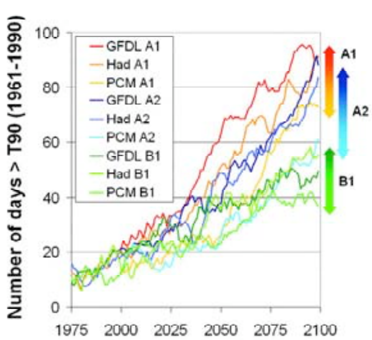

Figure 1. State-wide average number of JJAS T90 days/year from 1975 to 2100 for the HadCM3, GFDL and PCM models. Shaded arrows indicate the end-of-century range for simulations corresponding to the IPCC SRES A1fi (higher, red/orange), A2 (mid-high, blue) and B1 (lower, green) emission scenarios. Table 1. CDD *relative to the historical average* for five California cities, A1fi (higher), A2 (mid-high) and B1 (lower) using the HadCM3, GFDL2.1 and PCM downscaled output.

RELATED PUBLICATION

Miller, N.L., K. Hayhoe, J. Jin, and M. Auffhammer, Climate, extreme heat, and electricity demand in California. Journal of Applied Meteorology and Climatology, 47(6), 1834-1844), 2007.

ACKNOWLEDGMENTS

Support for this work is provided by the California Energy Commission and by the California Environmental Protection Agency as a contribution to the Governor's Climate Science Report. Work performed for the Department of Energy at Berkeley National Laboratory is under Contract No. DE-AC02-05CH11231.

The California Regional Climate Modeling Intercomparison and Climate Change Sensitivity Study

N.L. Miller, J. Jin, N. Schlegel, M. Synder, L.C. Sloan, M. Kanamitsu, H. Kanamaru, H. Hildago, P.B. Duffy, M.D. Dettinger, and D. Cayan
Contact: Norman L. Miller; 510/495.2374; nlmiller@lbl.gov

RESEARCH OBJECTIVES

The California Energy Commission (CEC) Public Interest Energy Research (PIER) Program is supporting research to develop probabilistic climate change scenarios for California. The objectives of this study are to develop climate scenarios with reduced uncertainties for applications by State planning agencies and impacts research. This project has two phases: (1) an enhancement and intercomparison of regional climate models (RCMs), and (2) a climate change sensitivity analysis for impact studies as part of the California Governors response to AB32.

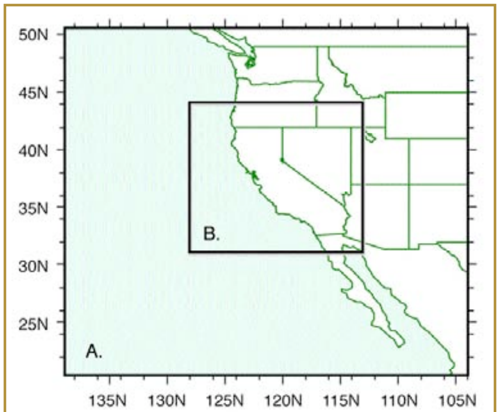

Figure 1. REBI domains and resolutions are (A) western U.S. and eastern Pacific Ocean, 30 km resolution, with coordinates of approximately [139W21N × 104W51N] and (B) California, Nevada, and eastern Pacific Ocean, 10 km resolution, with coordinates of approximately [128W31N × 113W44N].

APPROACH

Three RCMs—LBNL's version of the National Center for Atmospheric Research (NCAR) Weather Forecast and Prediction model version 2 coupled to the Community Land Model version 3 (LBNL/WRF-CLM3); UCSC's version of the Regional Climate Model version 3 (UCSC/RegCM3); and UCSD's version of the NOAA Regional Spectral Model (UCSD/RSM)—have been selected for model enhancements and intercomparison. The goal of the model enhancement is to implement key improvements prior to the January 2007 start of the model intercomparison aspect of this project. While the RCM codes were frozen for the comparison runs, each group continued to improve their model.

Each modeling group set up two nested domains, a western U.S. 30 km resolution domain, and a California 10 km resolution domain (Figure 1). The NCAR/NCEP Reanalysis II is the common input data for RCM initial and lateral boundary conditions, and model output variables and fluxes were mapped onto a common grid for intercomparison analysis.

ACCOMPLISHMENTS

During the enhancement period, we completed the WRF and CLM3 coupling and evaluation, as well as a series of one-year simulations of WRF using three land-surface schemes, for presentation at the WRF User's Workshop in May 2007 (Jin et al., 2007). We have also completed two 10-year simulations, one with the newly coupled WRF-CLM3 and one with the off the shelf WRF-RUC (Rapid Update Cycle) land-surface scheme.

SIGNIFICANCE OF FINDINGS

This RCM enhancement and intercomparison study is preparing the modeling groups for a comprehensive climate model bias and sensitivity analysis of projected climate change in California at fine scale. Understanding the details of model errors and how each model has propagated such errors further advances our probabilistic understanding of the potential consequences of climate change in California.

RELATED PUBLICATIONS

Kueppers, L.M, M.A. Snyder, L.C. Sloan, D Cayan, J. Jin, H. Kanamaru, M. Kanamitsu, N.L. Miller, Mary Tyree, H. Du, and B. Weare, Regional climate effects of irrigation and urbanization in the Western United States: A model intercomparison. CEC-500-2006-031, Global and Planetary Change (in press), 2006.

Jin, J., N.L. Miller, and N.J. Schlegel, Understanding the role of land surface processes in the Regional Climate System: A WRF modeling experiment. The 2007 WRF Workshop Proceedings, 2007.

Miller, N., et al., An analysis of simulated California climate using multiple dynamical and statistical techniques. CEC REBI Report, 49pp. The 2008 California Assessment Scenarios Project, Governor's California Assessment.

ACKNOWLEDGMENTS

Support for this work provided by the California Energy Commission and by the California Environmental Protection Agency as a contribution to the Governor's Climate Science Report. Work performed for the Department of Energy at Berkeley National Laboratory is under Contract No. DE-AC02-05CH11231.

Developing a Coupled Land Surface and Subsurface Model: CLMT2

Lehua Pan, Jiming Jin, Norman Miller, Yu-Shu Wu, and Gudmundur Bodvarsson
Contact: Lehua Pan, 510-495-2360, lpan@lbl.gov

RESEARCH OBJECTIVES

An understanding of the hydrologic interactions among atmosphere, land surface, and subsurface is one of the keys to understanding the water cycling system that supports our life system on Earth. Properly modeling such interactions is a difficult task because of the inherent coupled processes and complex feedback structures among subsystems. The objectives of this study are (1) to develop a new model of atmosphere-land-subsurface hydraulic interactions at watershed or regional scales by combining the best aspects of both CLM3 and TOUGH2; and (2) to show the importance of realistically modeling both surface and subsurface processes, as well as their interactions, in predicting the hydrologic responses to meteorological forces, by applying the new model to a watershed in Russia over an 18-year period.

APPROACH

The new model was developed by combining a state-of-the-art land-surface model, the NCAR Community Land Model version 3 (CLM3), with a variably saturated groundwater model, the TOUGH2, through an internal interface that includes flux and state variables shared by the two submodels. Specifically, TOUGH2, in its simulation, uses infiltration, evaporation, and root-uptake rates, calculated by CLM3, as source/sink terms; CLM3, in its simulation, uses saturation and capillary pressure profiles, calculated by TOUGH2, as state variables.

From the perspective of CLM3, the new model no longer simulates the subsurface moisture movement as a one-dimensional process by explicit scheme. Instead, the 3-D Richards equation is solved implicitly by TOUGH2. In particular, the assumption that the permeability decreases exponentially from top to bottom of the soil is no longer used, and the groundwater depth is no longer a parameter calculated as saturation-weighted depth. From the perspective of TOUGH2, the new model no longer takes the net infiltration or root uptake as a prescribed boundary condition or source/sink term. Instead, the net infiltration and root uptake result from simulations of coupled energy, wind, vegetation, and hydraulic processes by CLM3. As a result, CLMT2 expands the scope of TOUGH2 such that more realistic modeling of land-surface conditions is possible.

The 18 years of observation data from Usadievsky Watershed, Valdai, Russia, were used to evaluate the performance of this new model, as compared to the CLM3 model.

ACCOMPLISHMENTS

A model that combines the ability to simulate the land-surface and subsurface hydrologic responses with meteorological forcing, CLMT2, has been developed, by combining a state-of-the-art land-surface model, the NCAR Community Land Model version 3 (CLM3), and a variably saturated groundwater model, TOUGH2, through an internal interface that includes flux and state variables shared by the two submodels. The preliminary simulation results show that the coupled model greatly improves the predictions of the water table, evapotranspiration, surface temperature, and moisture in the top 20 cm of soil at a real watershed, as evaluated from 18 years of observed data.

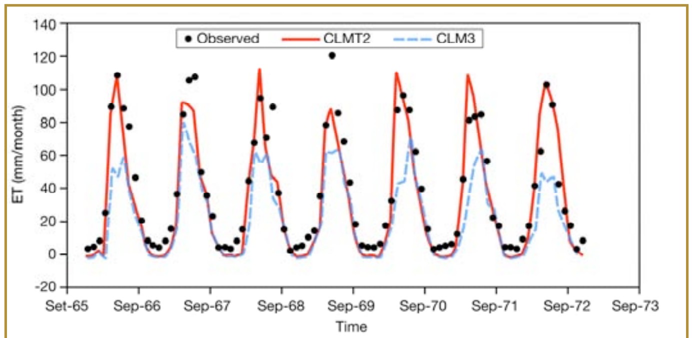

Figure 1. The observed (the dots) and simulated using CLMT2 (the red line) or CLM3 (the blue line) monthly ET.

SIGNIFICANCE OF FINDINGS

The results indicate that correct simulation of subsurface flow (including the water table) is very important, not only in assessing subsurface water resource itself, but also in simulating surface processes such as evapotranspiration or land-surface temperature, the two most important feedback factors for regional climate. The new model is a useful tool for simulating hydrologic systems at watershed or regional scale, especially the surface and subsurface responses to the climate changes.

RELATED PUBLICATION

Pan, Lehua, Jiming Jin, Norman Miller, Yu-Shu Wu, and Gudmundur Bodvarsson, 2006. Modeling hydraulic responses to meteorological force: From canopy to aquifer. LBNL-61018. Vadose Zone Journal (in press), 2007.

ACKNOWLEDGMENTS

This work was supported by Laboratory Directed Research and Development (LDRD) funding from Berkeley Lab, provided by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

WHERE DO FOSSIL FUEL CARBON DIOXIDE EMISSIONS FROM CALIFORNIA GO?

W.J. Riley, D.Y. Hsueh, M.L. Fischer, J.G. Hatch, D.E. Pataki, S. Cheong, M.L. Goulden, and J.T. Randerson
Contact: W.J. Riley, 510/486-5036, wjriley@lbl.gov

RESEARCH OBJECTIVES

It is widely recognized that climate is being impacted by anthropogenic fossil fuel CO_2 emissions (IPCC, 2001). Accurate quantification of fossil fuel CO_2 emissions is needed to properly account for climate change impacts, aid in policy development, improve climate prediction and climate change attribution, and aid in atmospheric inversion approaches to quantifying ecosystem C fluxes. Further, other primary atmospheric pollutants of interest (e.g., CO) are produced concurrently with CO_2, and emission estimates for these gases can be improved using accurate fossil fuel CO_2 emission and concentration (C_f) estimates.

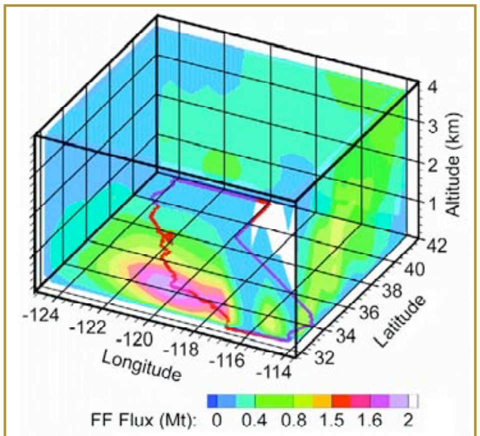

Figure 1. Cumulative annual fossil-fuel derived CO_2 transport out of California. The figures show contour plots on each vertical face of the cube surrounding California.

APPROACH

We applied radiocarbon (^{14}C) measurements in annual C_3 grasses across California to test a regional model (Riley et al., 2003; Riley et al., 2005) that simulates surface anthropogenic and ecosystem CO_2 fluxes, transport in the atmosphere, and the resulting $\Delta^{14}C$ value of annual grasses (Δ_g). The model was used to predict CO_2 transport patterns within and outside of California, (Riley et al., 2008).

ACCOMPLISHMENTS

The model accurately predicted statewide patterns of Δ_g. Predicted annual-averaged *Cf* were 14.0 ppm, 6.1 ppm, 4.8 ppm, and 0.3 ppm in Los Angeles, San Francisco, the Central Valley, and the North Coast, respectively. CO_2 emitted in Los Angeles and San Francisco was predicted to move into the Central Valley, raising *Cf* above that expected from local emissions alone. Annually, about 21%, 39%, 35%, and 5% of *Cf* leaves the California airspace to the north, east, south, and west, respectively (Figure 1), with large seasonal variations in the proportions. Correlations between Santa Ana wind conditions and both eastward and westward fluxes were observed.

SIGNIFICANCE OF FINDINGS

Our results indicate that state and continental scale atmospheric inversions need to consider fluxes in areas where measurements are sparse (e.g., over the ocean), transport within and across the marine boundary layer, and terrestrial boundary layer dynamics. Proposals have been made to use CO_2 measurements on the U.S. coastal boundaries to infer continental CO_2 emissions and exchanges. Our estimate—that a substantial portion of California's fossil fuel CO_2 emissions exits California in a relatively low elevation southward plume—implies that inversions need to accurately characterize these flows. Further, sampling protocols need to be designed to constrain estimates of these southward fluxes.

Other pollutants generated concurrently with CO_2 or from atmospheric photochemical reactions will also be impacted by the transport patterns described here. Model predictions indicated that portions of the Central Valley and northern Mexico had higher near-surface *Cf* than would be expected from local emissions alone. The additional loading resulted from transport from the San Francisco Bay, Sacramento, and Los Angeles air basins. Further research is required to characterize the impact of these transport patterns on ozone, NO_x, particulate matter, and N acid levels, and subsequent impact on local ecosystems, visibility, and human health.

RELATED PUBLICATIONS

Riley, W.J., C.J. Still, B.R. Helliker, M. Ribas-Carbo, and J.A. Berry, ^{18}O composition of CO_2 and H_2O ecosystem pools and fluxes in a tallgrass prairie: Simulations and comparisons to measurements. Global Change Biology, 9, 1567–1581, 2003.

Riley, W.J., J.T. Randerson, P.N. Foster, and T.J. Lueker, The influence of terrestrial ecosystems and topography on coastal CO_2 measurements: A case study at Trinidad Head, California. JGR-Biogeosciences, 110, 2005.

Riley, W.J., D.Y. Hsueh, J.T. Randerson, M.L. Fischer, J.G. Hatch, D.E. Pataki, W.W. Wang, and M.L. Goulden, Where do fossil fuel carbon dioxide emissions from California go? An analysis based on radiocarbon observations and an atmospheric transport model. JGR-Biogeosciences (in press), 2008.

ACKNOWLEDGMENTS

We gratefully acknowledge support from NASA (NNG05GD126), the Office of Science, U.S. Department of Energy (DE-AC02-05CH11231), and the National Science Foundation (0620176).

Interannual Regional CO_2 and Latent Heat Surface Fluxes in the Southern Great Plains: Measurements, Modeling, and Scaling

W.J. Riley, S.C. Biraud, M.S. Torn, M.L. Fischer, J.A. Berry, and D. Billesbach
Contact: W.J. Riley, 510/486-5036, wjriley@lbl.gov

RESEARCH OBJECTIVES

Characterizing net ecosystem exchanges of CO_2 (NEE) and energy exchanges in heterogeneous landscapes is notoriously difficult, yet critical given expected climate change and rapid development. We report here a three-year measurement and modeling study, conducted as part of the DOE Atmospheric Radiation Measurement Program and Berkeley Lab Carbon project, to improve our understanding of surface-to-atmosphere gas exchanges under highly heterogeneous land cover in the mostly agricultural U.S. Southern Great Plains Atmospheric Radiation Measurement Climate Research Facility (ACRF).

APPROACH

We combined multiyear site-level eddy covariance measurements in several of the dominant land-cover types with regional-scale climate data from the distributed Mesonet sampling stations and NEXRAD precipitation measurements, to calibrate a land-surface model of trace-gas and energy exchanges (ISOLSM; Cooley et al., [2005]; Riley et al., [2003]). Yearly variations in distributed vegetation cover type were estimated from archetypal phenology profiles and 250 m MODIS NDVI measurements. Soil hydraulic characteristics were determined from the USGS STATSGO 1 km resolution soil map. We first applied the model at a 250 m spatial scale to account for vegetation cover type and leaf area variations that occur on hundred-meter scales. Because of computational constraints, we developed a subsampling scheme within 10 km "macrocells" to perform these high-resolution simulations. The impact of spatial scale on predictions was determined using both a "dominant" vegetation cover approach and an approach that used the mean leaf area index (LAI) and fractional cover of each cover type.

ACCOMPLISHMENTS

Regional and subregional vegetation cover type estimates matched USDA census data well. Our results suggest that the ACRF region can be a net CO_2 source or sink to the atmosphere, depending on variations in climate and agricultural practices; large seasonal variations in CO_2 exchanges were also predicted (Figure 1). Predicted regional latent heat fluxes were largely independent of spatial scale of the model. However, both scaling approaches led to poor regional NEE estimates at all larger scales, and there was no quantifiable pattern in regional NEE between scales.

SIGNIFICANCE OF FINDINGS

Typical midday NEE variations across the ARM-SGP domain can be large (up to 25 μmol m^{-2} s^{-1}). Our results show that large errors in predicted NEE result when cover type and status variations are not explicitly accounted for at the scale of spatial variation. Further, the current approach of assuming a uniform crop cover and properties across the region leads to large errors in predicted regional NEE. Our approach allows us to quantify uncertainty in regional flux estimates associated with uncertainties in vegetation type, soil types, and spatial and temporal scaling of surface characterization and meteorological forcing. This work will benefit both "bottom-up" and "top-down" approaches to quantifying regional-scale surface CO_2 exchanges, as well as improving latent and sensible heat exchange estimates critical for boundary layer and cloud modeling.

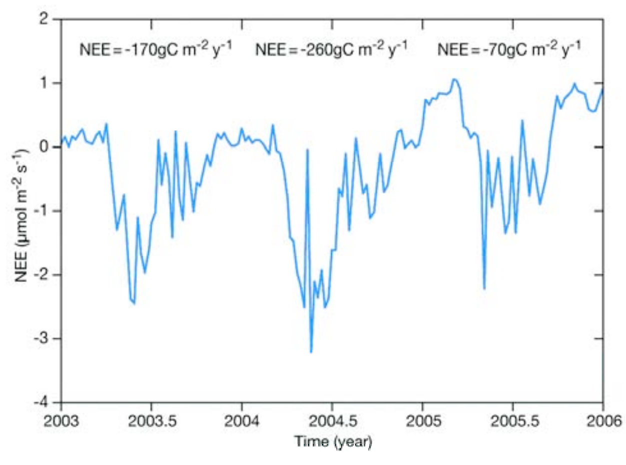

Figure 1. Predicted weekly NEE for the ACRF region. The region was predicted to be a net CO_2 sink in 2003 and 2004 and a net source in 2005.

RELATED PUBLICATIONS

Cooley, H.S., W.J. Riley, M.S. Torn, and Y. He, Impact of agricultural practice on regional climate in a coupled land surface mesoscale model. Journal of Geophysical Research-Atmospheres, 110, 2005.

Riley, W. J., C. J. Still, B. R. Helliker, M. Ribas-Carbo, and J. A. Berry, 18O composition of CO_2 and H_2O ecosystem pools and fluxes in a tallgrass prairie: Simulations and comparisons to measurements. Global Change Biology, 9, 1567–1581, 2003.

ACKNOWLEDGMENTS

This work was supported by the Director, Office of Science, Office of Biological and Environmental Research, Climate Change Research Division, Atmospheric and Radiation Measurements Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Modeling of Hydrology, The Nitrogen Cycle, and Vegetation Dynamics in Natural and Managed Ecosystems

W.J. Riley, F. Maggi, C. Gu, T. Xu, C.I. Steefel, N.L. Miller, and C.M. Oldenburg
Contact: W.J. Riley, 510/486-5036, wjriley@lbl.gov

RESEARCH OBJECTIVES

The biogeochemical nitrogen cycle and NO, N_2O, and CO_2 gas production in natural and agricultural ecosystems are impacted by several soil microbial populations, the hydrological cycle, plant dynamics, and climate. Understanding the release of NO, N_2O, and CO_2 from the soil surface to the atmosphere is a key factor in controlling greenhouse gas emissions, and assumes ever-greater importance in view of the foreseen increase in biofuel, food, and fiber production. The objective of this research is to develop a mechanistic analysis tool to investigate the effects of climate, irrigation, fertilizer application, and plant dynamics on N cycling and losses at site, watershed, and regional scales.

APPROACH

We have developed a coupled mechanistic modeling framework based on TOUGH2, TOUGHREACT, the CERES crop model, and the land-surface model CLM (the land-surface model used in the latest generation of the NCAR GCM). The framework includes various nitrification and denitrification pathways, multiple microbial biomass dynamics, hydrological dynamics, equilibrium and kinetic chemical reactions, landscape-scale hydrology, crop-specific plant growth and nutrient requirements, and natural ecosystem plant dynamics. Biotic and abiotic reactions are assumed to follow Michaelis-Menten kinetics, while biomass is assumed to follow multiple Monod growth kinetics accounting for electron donor, electron acceptor, and inhibitor concentrations. Water flow is modeled with the Darcy-Richards equation and advective, and diffusive tracer transport is modeled in both gaseous and liquid phases. The CERES crop model simulates plant biomass, N and water demand, and seed production (among others) across a range of crop phenotypes. Finally, CLM simulates the surface energy and radiation balance, natural ecosystem CO_2 exchanges, and distributed surface hydrology.

ACCOMPLISHMENTS

We have applied the model in two different agricultural systems and tested its performance against measurements of soil moisture, pH, NH_4^+, NO_2^-, and NO_3^- ion concentrations, and NO, N_2O, and CO_2 gas emissions (Gu et al., 2008; Maggi, et al., 2008). Good agreement between field observations and model predictions was found for all these quantities, as were variations associated with fertilizer type. We used the model to characterize gas emissions, solute leaching of several nitrogen species, and the vertical distribution of nitrifier and denitrifier populations associated with variations in fertilizer type and amount and irrigation practices. Preliminary analyses using the coupled model to analyze watershed scale behavior have been encouraging.

SIGNIFICANCE OF FINDINGS

In contrast to the predictions of most current coarse-scale models, all N losses increased nonlinearly with fertilizer and water application amount, and with fertilizer application depth (Figure 1). Further, different fertilizer types resulted in substantially different N-loss patterns over time, and these patterns depend strongly on soil properties. Our results imply that typical field, watershed, and regional-scale assessment approaches for ecosystem N balance and losses need to be revised.

RELATED PUBLICATIONS

Gu, C., et al., Aqeuous and gaseous nitrogen losses induced by fertilizer application. JGR-Biogeosciences (submitted), 2008.

Maggi, F., et al., A mechanistic treatment of the dominant soil nitrogen cycling processes: Model development, testing, and application. Journal of Geophysical Research-Biogeosciences, 113, 2008.

ACKNOWLEDGMENT

This work was supported by Laboratory Directed Research and Development (LDRD) funding from Berkeley Lab, provided by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

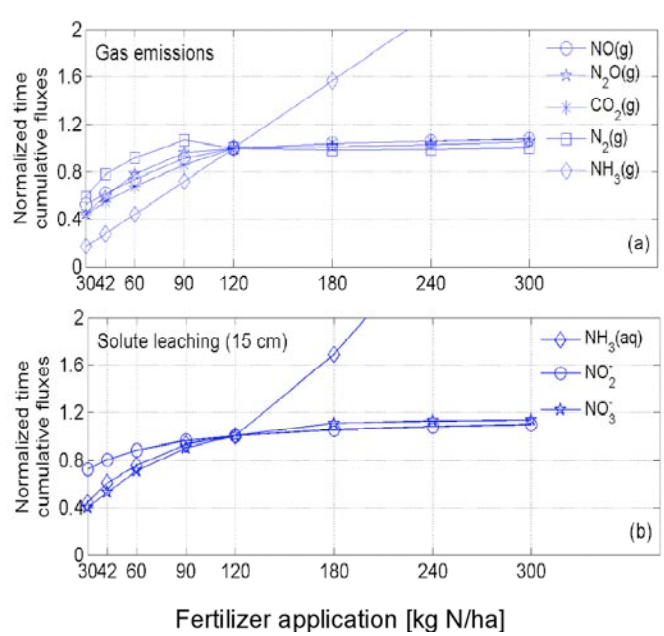

Figure 1. (a) Cumulative normalized gas fluxes and (b) leachate fluxes measured at 15 cm depth as functions of fertilizer amount. Fluxes are normalized to those corresponding to a fertilizer application of 120 kg N ha^{-1}.

Carbon Cycling in the Southern Great Plains During the ARM Cumulus-Land Surface Interaction Campaign (CLASIC)

Margaret S. Torn, Marc L. Fischer, William J. Riley, Sébastien Biraud, and J. Berry
Contact: Margaret S. Torn, 510/495-2223, MSTorn@lbl.gov

RESEARCH OBJECTIVES

The DOE Atmospheric and Radiation Measurement (ARM)/Berkeley Lab Carbon Project is making a coordinated suite of carbon concentration, isotope, and flux measurements to support climate modeling studies and the North American Carbon Program, including quantifying regional atmospheric CO_2 sources and sinks, and implementing land-surface models for estimating regional carbon, water, and energy fluxes. During the ARM Cumulus-Land Surface Interaction Campaign (CLASIC), we collected airborne measurements for CO_2 source attribution, which included (for example) characterizing the chemical fingerprint of anthropogenic greenhouse gas emissions.

APPROACH

CLASIC brought together eight aircraft, one helicopter, and over thirty scientists in June 2007, to study the influence of the land surface on cloud development and atmospheric dynamics, including greenhouse gas fluxes and concentrations. We planned carbon-centered flight paths, integrated instrumentation on a Cessna 206 and the CIRPAS Twin Otter, and helped coordinate deployment of 10 eddy flux towers by DOE, USDA, and NASA for land-surface studies.

ACCOMPLISHMENTS

We flew 22 flights with continuous CO_2, NOAA flasks and $^{14}CO_2$ flasks, nine of which also had continuous CO and CH_4 concentration measurements. All of these data sets have been processed and submitted to the CLASIC data archives. Results from the campaign have been presented at the CLASIC workshop and other scientific meetings, and are being integrated into the NACP Mid-Continent Intensive that took place in summer 2007, and other NACP synthesis activities. Here, we give results for anthropogenic source characterization.

On June 22, 2007, the CIRPAS Twin Otter flew an anthropogenic source characterization mission around Oklahoma City, Oklahoma (OKC), flying most of the time at 4,000 ft above ground level (Figure 1a). Figure 1b shows continuous CO_2 (black dots), and flask CO (red dots) concentrations during the flight. The blue line shows background CO_2 concentrations measured continuously at the CF 60 m tower (green square shown on Figure 1a). Note that these background CO_2 concentrations decrease during the day as a result of plant uptake, while fossil sources in OKC elevate CO_2 and CO concentrations. The NOAA flasks will provide concentrations of multiple hydrocarbon species to relate to the CO_2 signal.

SIGNIFICANCE OF FINDINGS

The results demonstrate that we can use simultaneous analysis of multiple species to differentiate anthropogenic versus natural influences on atmospheric CO_2 (and other species),

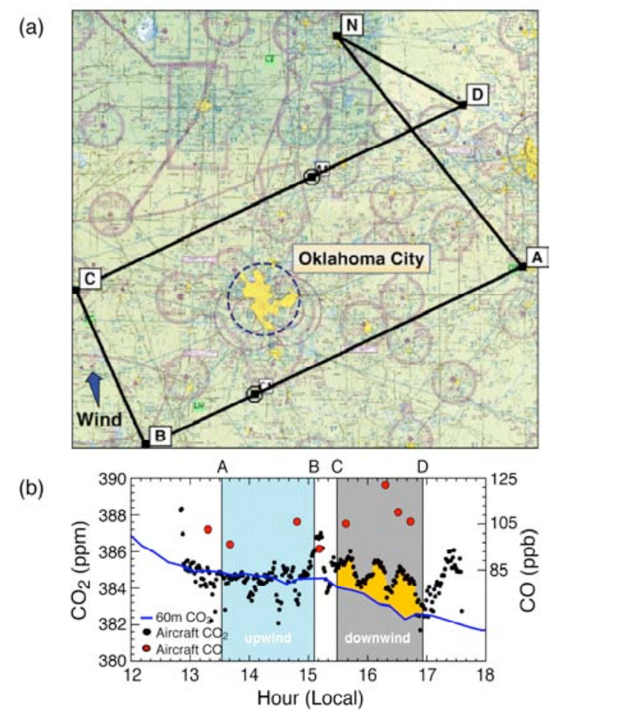

Figure 1. (a) Map showing the flight pattern flown by the CIRPAS Twin Otter on June 22, 2007; (b) Time series of continuous CO_2 and flask CO concentrations measured during the mission. The prevailing wind was from the south.

upwind and downwind of OKC. Further analysis of CO, CH_4, $^{13}CO_2$, and $^{14}CO_2$ will allow quantitative partitioning of anthropogenic emissions and biosphere fluxes. Developing a quantitative fingerprint for anthropogenic emissions is important for verifying fossil fuel emissions inventories, estimating biosphere CO_2 fluxes, and closing the North American carbon budget.

RELATED PUBLICATIONS AND RESOURCES

CLASIC Science Plan, 2007. http://www.arm.gov/publications/programdocs/doe-sc-arm-0703.pdf
ARM Carbon Web Site: http://esd.lbl.gov/ARMCarbon/

ACKNOWLEDGMENTS

This work was supported by the Director, Office of Science, Office of Biological and Environmental Research, Climate Change Research Division, Atmospheric and Radiation Measurements Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, and in-kind contributions from NOAA-ESRL, Lawrence Livermore National Laboratory, and Carnegie Institution of Washington.

Missing Feedbacks, Asymmetric Uncertainties, and the Underestimation of Future Warming

Margaret S. Torn and John Harte
Contact: Margaret S. Torn, 510/495-2223, MSTorn@lbl.gov

RESEARCH OBJECTIVES

Historical evidence shows that atmospheric greenhouse gas (GhG) concentrations increase during periods of warming, implying a positive feedback to climate change. However, current general circulation models (GCMs) include only a subset of the possible GhG feedback processes—for example, methane processes are not included at all. We quantified the potential CO_2 and CH_4 feedback and explored the implications of positive feedback for climate risk.

APPROACH

To achieve a comprehensive accounting, we used a simple model combined with ice core data, which integrate over all active processes, rather than a detailed simulation model that could only capture a few processes. Specifically, we quantified climate-GhG feedbacks by combining the mathematics of feedback from engineering literature with (1) empirical ice-core data from the past 320,000 years and (2) general circulation model climate sensitivity from nine GCMs (1.2ºC/275 ppm CO_2 equivalent, in the absence of other feedbacks).

The strength of GhG feedbacks was estimated by the overall gain in the system—how much the final temperature change, ΔT_F was amplified or dampened from an initial perturbation, ΔT_0 .The feedbacks currently in GCMs—mainly water vapor, cloud, and ice-albedo processes—amplify the direct effect of doubled-CO_2 (1.2ºC) to a total warming of 1.5–4.5ºC, meaning they have a gain of 0.20–0.73 without GhG feedbacks (see equation in Figure 1). When we add the GhG gain to the existing climate model gain, the total gain is 0.27–0.8.

ACCOMPLISHMENTS/FINDINGS

The feedback gain from greenhouse gases alone is fairly small. Each new increment of feedback, however, has an increasingly larger effect on the final temperature (see Figure 1). As a result, adding the GhG to the existing feedbacks greatly amplifies any climate perturbation. In fact, an emissions scenario that would currently be predicted to result in 1.5–4.5 ºC warming would actually result in 1.6–6.0ºC warming at equilibrium. In other words, adding the small GhG gain results in up to 1.5ºC warmer temperatures than currently predicted for emissions that would double atmospheric CO_2 concentrations. That is because instead of merely doubling concentrations, those anthropogenic emissions would be matched by a kind of natural "matching fund." This additional feedback thus takes place because anthropogenic GhG emissions cause warming, which alters earth system processes, resulting in additional atmospheric greenhouse gas loading and additional warming.

SIGNIFICANCE OF FINDINGS

The GhG feedbacks greatly increase the warming commitment engendered for any given anthropogenic emissions scenario. Moreover, systems with positive feedbacks have a higher probability of experiencing the upper range of predicted change rather than the lower end. In other words, the presence of positive feedbacks means that there is a higher risk that we will experience more severe, not less severe, climate change than is currently forecast.

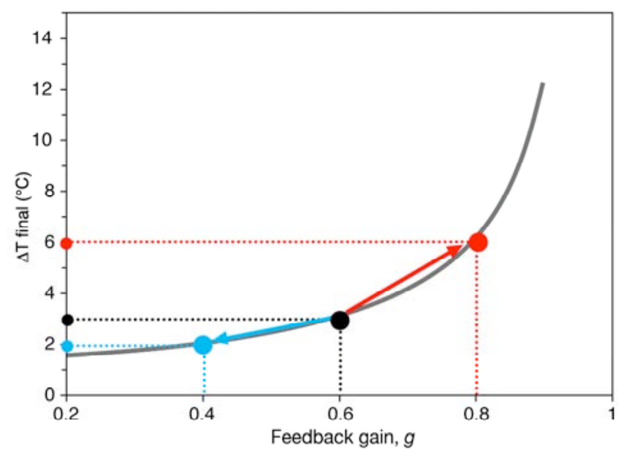

Figure 1. This graph of the feedback equation (inset in Figure) illustrates that a change or uncertainty in the feedback has an asymmetric effect, meaning that a +0.1 increase in feedback gain, g, has much bigger effect on temperature than does a -0.1 decrease. In the example shown here, the direct warming (ΔT0) is 1ºC, nominal g = 0.7 and nominal final warming (ΔTF) = 3.3 ºC. An additional 0.1 negative feedback (g = 0.7 - 0.1 = 0.6) results in a warming of 2.5ºC (0.8ºC lower than the nominal case), whereas the same magnitude of change or uncertainty in the positive direction (g = 0.7 + 0.1 = 0.8) results in a 5ºC warming (1.7ºC higher).

RELATED PUBLICATIONS

Torn, M.S. and J. Harte, Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming. Geophys. Res. Lett., 33, L10703, doi:10.1029/2005GL025540, 2006.

Intergovernmental Panel on Climate Change, Climate Change 2007—The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 996 pp., Cambridge University Press, Cambridge, UK, 2007.

ACKNOWLEDGMENTS

This work was supported by the Director, Office of Science, Office of Biological and Environmental Research, Climate Change Research Division, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, and the National Science Foundation under Contract No. DEB0211025. We thank K. Cuffey for access to the ice core data.

Characterizing Root Dynamics in Forests: Estimates Using Radiocarbon Data and Numerical Modeling

M. S. Torn, W. J. Riley, J. B. Gaudinski, John D. Joslin, Paul Hanson
Contact: Margaret S. Torn, 510/495-2223, MSTorn@lbl.gov

RESEARCH OBJECTIVES

In a typical year, terrestrial plants assimilate about twenty times as much CO_2 as is produced through fossil fuel combustion. Of the assimilated carbon, most is rapidly respired back to the atmosphere, but a substantial fraction is used to build plant tissues. Root carbon (C) dynamics represent an important and poorly characterized component of these ecosystem C exchanges. Our goal in this research was to improve the conceptual representation of fine root (<2 mm diameter) C flows in a numerical model applicable to site, regional, and global analyses.

APPROACH

We used a whole-ecosystem ^{14}C label to explore fundamental concepts of how carbon cycles through roots, and to develop, parameterize, and test a model (Radix1) of fine-root mortality and decomposition. Carbon-14 measurements from two root size classes at three soil depths, tree rings, and soil respiration, along with ancillary data on belowground primary production and specific root respiration rates at a temperate forest in Oak Ridge, Tennessee, were used in the development of Radix.

ACCOMPLISHMENTS

In contrast to previous models of fine root C dynamics, the 14C measurements (Figure 1) from the Oak Ridge site clearly indicated the need for a storage pool to support root growth in some seasons and at least two C pools each for live and dead fine roots (Riley et al., 2008). We developed *Radix* to simulate two live root pools (one with structural and nonstructural C components), two dead root pools, non-normally distributed root mortality turnover times, a stored C pool, and seasonal growth and respiration patterns. The turnover time through the stored C pool was estimated to be ~0.7 years (Gaudinski et al., 2008), while root lifetimes were ~1 and 10 years for the fast and slow live-root pools, respectively (and similar for the fast and slow dead-root-pool decomposition turnover times). Interpretation of root ^{14}C measurements was strongly affected by root respiration estimates.

SIGNIFICANCE OF FINDINGS

We conclude that accurate characterization of C flows through fine roots requires a model with two live fine-root pools, two dead fine-root pools, storage, and root respiration. Root turnover times on the order of a decade imply substantially different response times in biomass and growth than are currently predicted by models with a single, relatively fast turnover pool. These results have a substantial impact on predictions for the amount of C that moves into soil organic matter, and hence on overall ecosystem C dynamics in forested ecosystems.

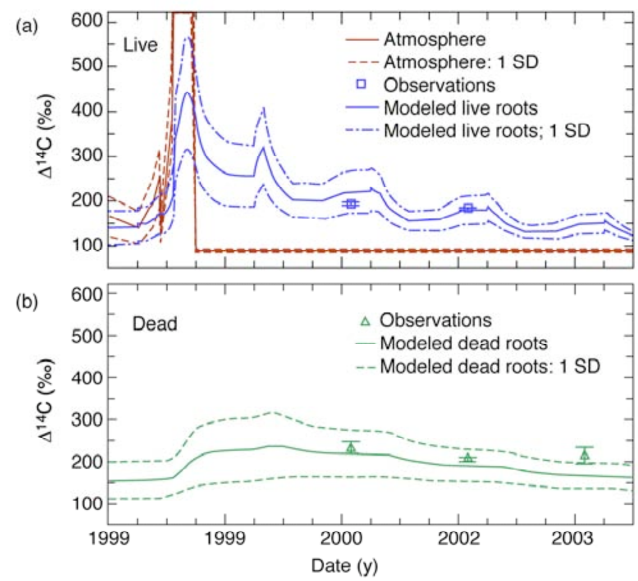

Figure 1. The measured $\Delta^{14}C$ values for (a) live (L, square) roots and (b) dead (D, triangle) roots that are < 0.5 mm diameter from 0–15 cm depth, with *Radix* model predictions (solid lines ± standard deviation), using best-fit root turnover times. For reference, the $^{14}CO_2$ values of the local (i.e., labeled) atmosphere are shown in red.

RELATED PUBLICATIONS

Gaudinski, J.B., W.J. Riley, M.S. Torn, J.D. Joslin, and P.J. Hanson, Quantification of root lifespan and stored carbon reserves to new root growth using radiocarbon data and a multi-compartment model. Global Change Biology (in press), 2008.

Riley, W.J., J.B.Gaudinski, M.S. Torn, J.D. Joslin, and P.J. Hanson, Fine-root mortality in a temperate forest: Estimates using radiocarbon data and numerical modeling. Global Change Biology (submitted), 2008.

ACKNOWLEDGMENTS

This work was supported by the Terrestrial Carbon Processes and Carbon Sequestration Programs, Office of Science, U.S. Department of Energy under Contract No. DE-AC02-05CH11231.